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Geospatial and environmental analysis of road traffic accidents in the city of Resistencia, Argentina

Análisis espacial y del entorno físico de accidentes de tránsito en la ciudad de Resistencia, Argentina

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ABSTRACT Traffic accidents are an emerging problem in cities with high mobility and little urban planning. Evidence is lacking in Argentina regarding the relationship between the environment and accident occurrence; we therefore conducted a geospatial analysis and estimated the risk of accidents and their possible association with the characteristics of the physical environment in the city of Resistencia, Argentina occurring in 2012. Kernel density estimates were used for the spatial distribution of accidents and in parallel an observational, analytical study was carried out to analyze the factors associated with accident occurrence. The results show three critical areas (in the northwest, center and south of the city) with greater accident frequency. Environmental factors that were associated with the occurrence of accidents were the presence of street lighting (23% greater), the presence of a tree close to the road (47% greater), the presence of a traffic light (28% greater), and if the road was a major avenue (122% greater) and had curves (129% greater). This study shows the city of Resistencia to be in a situation of urban vulnerability due not only to its socioeconomic status but also to the unequal development compared to neighboring cities, a reality that fosters an unfavorable environment.

KEY WORDS Geographic Information Systems; Spatial Analysis; Traffic Accidents; Environment; Argentina.

RESUMEN Los accidentes de tránsito constituyen un problema emergente en ciudades con alta movilidad y baja planificación urbana. No existe suficiente evidencia en Argentina acerca de la relación entre el entorno y la ocurrencia de accidentes. Por ello, realizamos un análisis espacial de ocurrencia y estimamos el riesgo de ocurrencia de accidentes en el año 2012 y su posible asociación con las características del entorno físico en la ciudad de Resistencia, provincia del Chaco, Argentina. Para el análisis espacial de los accidentes se utilizó la estimación de densidad kernel. Luego, a través de un estudio observacional y analítico se procedió a analizar los factores asociados a la ocurrencia de los accidentes. Los resultados muestran que existen tres zonas críticas (noroeste, centro y sur) con mayor frecuencia de accidentes. Los factores del entorno que estuvieron asociados con la ocurrencia de accidentes fueron la presencia de iluminación vial (23% menor), árbol próximo a la calzada (47% mayor), la presencia de semáforo (28% mayor), avenidas (122% mayor) y disposición curva de la calzada (129% mayor). Este estudio ubica a la ciudad de Resistencia en una situación de vulnerabilidad urbana, no solo por el contexto socioeconómico donde se encuentra sino por el desigual desarrollo territorial que presenta respecto a las ciudades vecinas, que propicia un entorno desfavorable.

PALABRAS CLAVES Sistemas de Información Geográfica; Análisis Espacial; Accidentes de Tránsito; Ambiente; Argentina.

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INTRODUCTION

Unintentional injury fatalities have become an important public health problem given the continued increase in mortality due to this cause over time.[1] In just 2010, 9.6% of all deaths worldwide were attributable to unintentional injuries, of which 1.3 million were due to traffic accidents.[2] It is estimated globally that the costs generated by traffic accidents reach over 500 billion dollars, with 65 billion in costs corresponding to low- and middle-income countries, where over 90% of all of these deaths occur.[3,4]

In Argentina in 2007, it is estimated that 5,914 deaths due to traffic accidents occurred,[5] going from the sixth cause of potentially productive years of life lost (PPYLL) due to premature death in 2005 to the fourth cause in 2015.[6] At the same time, certain provinces of the country like Santa Fe, Chaco and Córdoba reported high accident levels, which in turn provoked an increase in morbidity and mortality.[7] Given that this scenario could persist into the future, it is necessary to study in greater depth the local factors associated with accident occurrence.

Within the transit system, the physical environment is one of the fundamental elements in determining the risk factors that come into play during the day-to-day mobility of the population. A number of studies reveal the influence of the material conditions of roads in the behavior of those who use them and in the generation of traffic accidents.[8,9] These conditions are related to the density of street lighting, street design, and the presence of crosswalks, among others.[10,11,12] Nevertheless, in many Argentine cities the way in which the built environment positively or negatively influences traffic accident occurrence has not been studied.

At present, geographic information systems (GIS) applied to health research with a spatial or territorial perspective are being used in the study of traffic accidents. In Argentina, some studies have used these systems and show their utility in exploring accident patterns or identifying areas of greater risk.[13,14,15] In this way, GIS can be useful in areas with elevated traffic accident frequency so as to aid implementation of possible preventive measures.

The general objective of this research was to study the patterns in traffic accident occurrence through a geospatial analysis of accident sites for the year 2012 in the city of Resistencia, province of Chaco, Argentina. The risk of accident occurrence and possible associations with characteristics of the physical environment were also analyzed.

MATERIALS AND METHODS

Study design and environment

An analytical, cross-sectional and spatial study was carried out using police records of traffic accidents which occurred during the year 2012, taking as the area of study the city of Resistencia, capital of the province of Chaco, in northeastern Argentina. Resistencia is the most populated city of the province and is the primary economic and cultural center; it is also one of the most important cities in the larger northeast region of Argentina. It is located in the department of San Fernando and has 390,874 inhabitants.[16]

Dependent or outcome variable

The outcome considered in the study for both the spatial and physical environment analysis was the *frequency of accidents*. Two units of analysis were considered: the spatial unit of analysis was the street address where the accident occurred, while the unit of observation for the environmental factors was defined as the surroundings within a 20 meter radius from the point of the accident. This value was chosen based on the minimum distance needed for a vehicle to come to a stop according to the braking distance equation (considering an average velocity of 40 km/hr).[17] An accident was considered to be any unintentional collision

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between two or more mobile units on a road, regardless of the result (injury/death).

Independent variables

The independent variables considered for the analysis of the physical environment were: a) *the type of road*, including avenues, streets and highways, identified according to the cadastral plan and verified through direct observation; b) *the origin of the road*, either the central plaza (primary origin) or a main road (secondary origin), identified according to the cadastral plan and verified through direct observation; c) *the presence of street lighting,* or any mechanism of artificial illumination (lamppost or hanging lamp) found within the surroundings, the functioning of which was verified by a key informant; d) *the presence of a bike lane*, that is, any lane with indication that it may be used for the circulation of bicycles, or any independent lane where bicycle traffic is permitted, near where the event occurred; e) *the presence of a tree near the road*, considering all trees at a distance less than or equal to 20 meters from the site of the accident that impair the visualization of the surrounding area; f) *the shape of the road*, which could be straight, curved or winding; g) *whether the road is paved* upon visual inspection of the site of the event; h) *the presence of raised elements to reduce speed*, any mechanism placed on the surface of certain sections of the road in the proximity of the accident (for example, raised crosswalk, speedbumps); and i) *the presence of a stoplight* at the intersection closest to the accident.

Data collection techniques and instruments

The variables were collected in an *ad hoc* data recording sheet in the period from July to December 2012. The physical environment surrounding the places where the traffic accidents occurred according the local police reports was inspected and the street addresses were geocoded in two stages. In the first, the coding was carried out with the program Batchgeo and with Google Maps. In the second, for the sites that could not be properly identified through these methods, the coordinates were registered *in situ* through a Garmin GPS device, model eTrex Legend® HCx.

Based in Google Maps, maps were created overlaying the sites (points) where accidents occurred onto the different census tracts of the city. Each surveyor was provided with a map delimiting the census tracts of interest and an *ad hoc* form with which to collect data regarding the physical environment. A database was developed using the program Microsoft Excel® 2013. The staff were trained in the use of the GPS device and in filling out the observation sheet, with each operator receiving a training manual. A pilot test was carried out with five randomly selected points in order to carry out the visual inspection of the environment. After the data collection process, the data were analyzed in two phases.

Data analysis

In the first phase, the program ArcGIS Desktop version 10.4 (ESRI Inc., Redlands, CA, USA) was used to project each geo-referenced point into the shapefile (.shp) format. Using the technique of kernel density (Guassian kernal density per km^2) with a predetermined bandwidth and cell size of 30, the relationship between the points was estimated to classify in regular intervals those areas with high (in red), medium (in yellow) and low (in blue) density for the event. This technique analyzes the relationship among a number of points or geographic events (for example, georeferenced accident sites), in such a way that the points closest together generate areas of greater frequency (density) within a determined area. A density layer was generated with the 1,342 points. The shapefiles created were connected and projected onto OpenStreetMaps.

Next, in the second phase, associations with the environmental variables were

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sought through the statistical package Stata® v14.1. The categorical variables were described through absolute and relative frequencies. For the bivariate and multivariate statistical analysis, generalized linear models (GLM) of the Poisson family and the link-log function were used, taking as the outcome variable the traffic accident frequency. Given the multifactorial causality of traffic accidents and that the analysis is cross-sectional, our regression model was not constructed to analyze predictive capacity but rather the relations and associations among the dependent and independent variables. For the multivariate analysis, the variables included were those that showed minimal association with the dependent variable, and mean expected frequency quotients (MFQ) for accidents were calculated with 95% confidence intervals (95% CI). For all the analyses a *p*-value of <0.05 was considered statistically significant.

Ethical considerations

The study did not require the approval of an ethics committee as the analysis utilizes secondary data (police records) that do not allow the identification of those involved in the traffic accidents.

RESULTS

Of the 2,500 events registered in 2012, it was possible to georeference 1,342 traffic accidents that occurred in the urban area of the city of Resistencia. Of these, the survey of the physical environment was carried out for 462 points, given that many accidents took place in the same area (Figure 1).

The application of Kernel density allowed spatial distribution patterns to be identified that would orient the interpretation of the results. For this purpose, the density of occurrence of these accidents was represented in four classes: a) very high, b) high, c) medium, and d) low. In Figure 2 it can be observed that the very high density areas are found in the southeastern part of the city of Resistencia. In this sector, two areas can be discerned: one at the intersection of Av. 9 de Julio and Ildefonso Pérez Street and the other at the intersection of Av. Juan José Castelli and Av. Arribalzaga. With respect to the areas of high traffic density, three places can be seen: in the northwestern part of the city, Av. 25 de Mayo at the 2500 block and Av. Carlos María de Alvear at the 3300 block (the administrative border between the cities of Fontana and Resistencia); and in the southeastern part, at the intersection of Av. Edison and Av. Arribalzaga. In addition, six areas with medium traffic accident density were identified (Figure 2).

In the analysis of the physical environment surrounding the areas with very high density of accidents, the following characteristics were observed:

1) Av. 9 de Julio and Pérez Street: The streets are part of the urban grid. There are no stoplights nor speed reduction elements, nor are there horizontal signs (such as road markings for pedestrian crossing). Pérez Street (which is asphalted) is one-way, exiting the Luzuriaga neighborhood of the city of Resistencia, however culturally it is used as a two-way street. Regarding the lighting, two appropriately functioning streetlamps were observed.
2) Av. Juan José Castelli and Av. Arribalzaga (or 21st Street): This is the intersection of two primary avenues of the city. There are stoplights before the crosswalk and the intersection. The area is one of the most populated in the city.

Similarly, high density areas of traffic accidents showed the following characteristics in the physical environment:

1) Av. 25 de Mayo, 2500 block: It is the extension of the avenue (asphalted) and its connection with National Route 11. No streetlights can be seen, nor horizontal or vertical signage of any kind. It is a two-way avenue (entering and exiting the city of Resistencia), with the axis entering the city

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connected to Campias Street (asphalted). No traffic signs regarding this connection and no public streetlamps were observed.

2) Av. Carlos María de Alvear, 3300 block: At the intersection of Alvear (asphalted) and Lago Nahuel Huapi Street (unpaved). The latter is the administrative border between Resistencia and Fontana. In the physical environment, no evidence of stoplights or vertical or horizontal signage could be seen. No elements that would block vision, such as trees or advertising signs, were observed.

3) Av. Edison and Av. Arribalzaga: Both avenues are unpaved, there are no stoplights nor any type of horizontal or vertical signage. No public streetlamps were identified.

Regarding the general characteristics of the environment (Table 1) it is observed that in

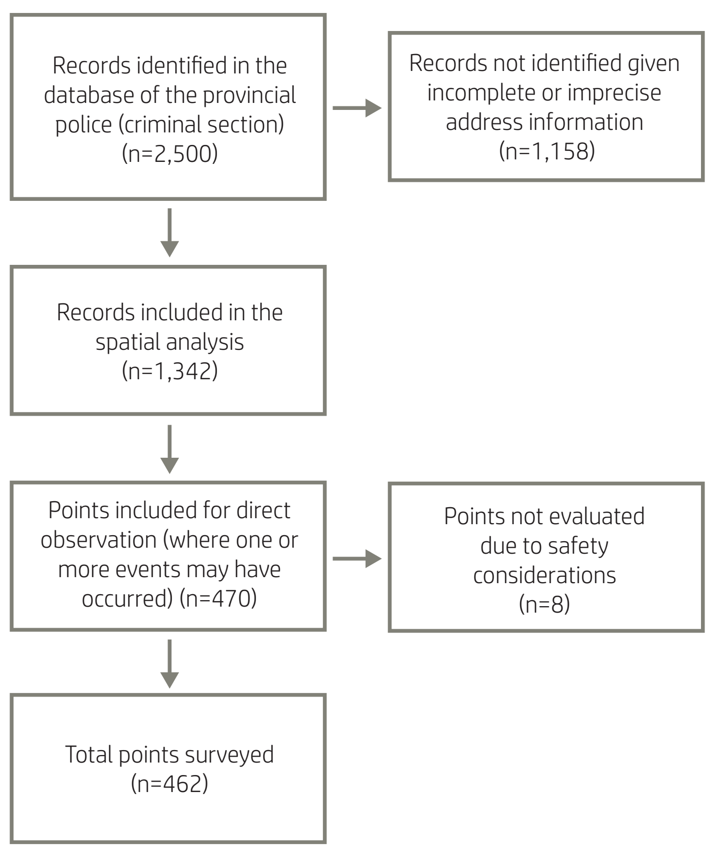

Figure 1. Flowchart of information on traffic accidents examined. Resistencia, Chaco, Argentina, 2012.

Source: Own elaboration based on data from the crime department of the Chaco Police.

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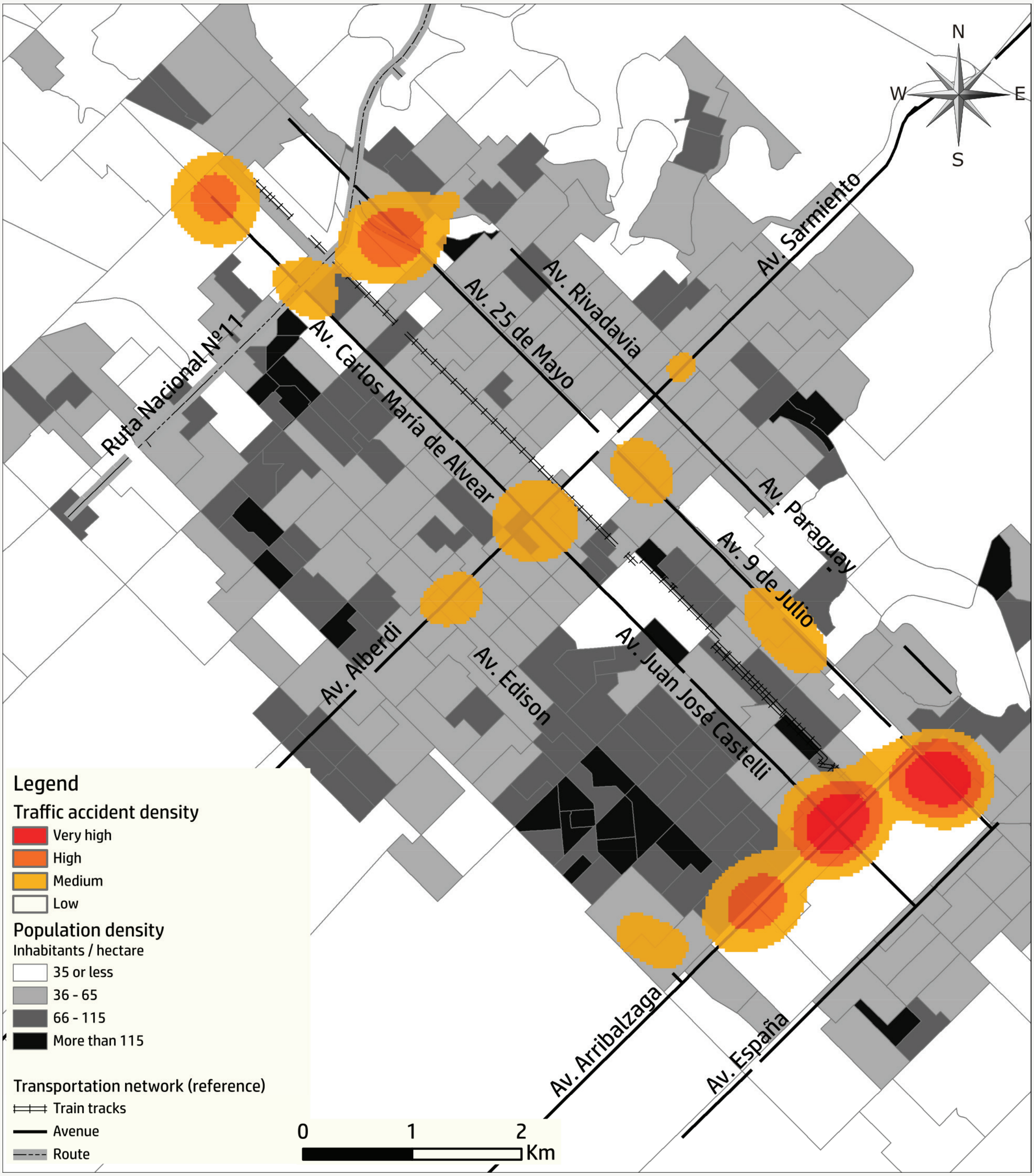

Figure 2. Spatial analysis of the density of traffic accidents in the urban area of the city of Resistencia, Chaco, Argentina (N=1,342).

Source: Own elaboration based on data from the crime department of the Chaco Police and the National Census of Populations and Households 2010.

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Table 1. Characteristics of accidents according to physical environment variables in Resistencia, Chaco, Argentina, 2012 (N=462).

Characteristics	Frecuency	%
Facilitators and barriers		
Street lighting*	330	71.74
Bike lane	46	9.96
Tree near the road	63	13.64
Speed reduction		
Stoplight	47	10.17
Raised speed reducers**	63	13.73
Road		
Paved	338	73.16
Type of road		
Avenue	290	62.77
Street	168	36.36
Route	4	0.87
Road origin		
Primary	168	36.36
Secondary	294	63.64
Road shape		
Straight	433	93.72
Curved	17	3.68
Winding	12	2.60

Source: Own elaboration based on direct observation data.
*N=460; ** N=459

the places with accident frequency: streetlamps were present (71.74%), the roads were paved (73.16%), the roads in question were avenues (62.77%), of secondary origin (63.64%), and straight in shape (93.72%). Regarding speed reduction, 10.17% had a nearby stoplight and 13.73% had elevated speed reduction elements. Additionally, in 13.64% of the environments there was a tree near the road.

Regarding associated factors (Table 2), in the bivariate analysis the presence of bike lanes, raised speed reducers, paved roads and road origin were not significantly associated with the frequency of traffic accidents. Nevertheless, in both the bivariate and multivariate analysis the presence of street lighting, a tree near the road, and stoplights, as well as the type and shape of the road, were associated in a statistically significant way.

The presence of streetlamps lowered the average frequency of traffic accidents by 23%, however the presence of a tree nearby raised frequency by 47% and the presence of a stoplight raised accident frequency by 28%. Additionally, the average accident frequency for avenues was 2.2 times greater than that of routes, while the average frequency on streets was 1.23 times greater than that of routes. On curved streets the average frequency of

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Table 2. Association among physical environment variables and and frequency of accidents at each accident site, Resistencia, Chaco, Argentina (N= 460).

Characteristics	Crude MFR			Adjusted MFR		
	MFR	95% CI	*p-value*	MFR	95% CI	*p-value*
Street lighting present						
Yes	0.78	0.68-0.89	<0.001	0.77	0.67-0.88	<0.001
No*	-	-	-	-	-	-
Bike lane present						
Yes	0.94	0.75-1.16	0.570	-	-	-
No*	-	-	-	-		
Tree present next to the road						
Yes	1.46	1.24-1.71	<0.001	1.47	1.24-1.73	<0.001
No*	-	-	-	-	-	-
Stoplight present						
Yes	1.26	1.05-1.53	0.013	1.28	1.05-1.56	0.012
No*	-	-	-	-	-	-
Raised speed reducers present						
Yes	0.96	0.80-1.16	0.720	-	-	-
No*	-	-	-	-	-	-
Road paved						
Yes	0.94	0.82-1.10	0.460	-	-	-
No*	-	-	-	-	-	-
Type of road						
Avenue	3.74	2.52-5.54	<0.001	2.22	1.42-3.45	<0.001
Street	1.25	1.09-1.43	0.001	1.23	1.07-1.42	0.003
Route*	-	-	-	-	-	-
Road origin						
Secondary	0.96	0.85-1.10	0.630	-	-	-
Primary*	-	-	-	-	-	-
Road shape						
Straight	0.82	0.52-1.28	0.390	0.71	0.45-1.12	0.148
Curved	2.64	2.13-3.28	<0.001	2.29	1.80-2.92	<0.001
Winding*	-	-	-	-	-	-

Source: Own elaboration based on directly observed data.
Note: *Reference value. MFR = Mean frequency ratio. 95% CI = 95% confidence interval.

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accidents was also greater as compared to winding streets (2.29 times greater).

DISCUSSION

The findings of this study show areas vulnerable to high traffic accident frequency in three key areas of the city (the northwest, center and south); these higher numbers are associated with certain features of the physical environment that have significant influence.

Geographically, Resistencia holds a central and strategic place with respect to other cities of the Argentine northeast like Fontana, Barranqueras and Puerto Vilelas, all of which together form what is known as the Greater Resistencia Metropolitan Area [*Área Metropolitana del Gran Resistencia*] (AMGR). This geographic location represents a dimension of analysis that should be considered in studies of daily mobility, for the direct relationship it has with the structural characteristics of circulation that show territorial inequalities.(18)

The AMGR is an important administrative, commercial and service provision center; it concentrates the largest offer of services as well as the best indicators in housing, education and health in a province with a high index of poverty. Its centrality and the better living conditions reproduce and deepen the unequal relationship Resistencia holds with respect to the other municipalities that form part of the AMGR.(19)

In these terms, Av. 9 de Julio and Av. Juan José Castelli (which are parallel, according to the urban grid), along with Av. Soberanía Nacional, Av. 25 de Mayo and Av. Carlos María de Alvear, represent the primary axes connecting the city of Resistencia with the neighboring cities. This situation helps to explain the high density of accidents occurring in the previously described areas. This justification is based on the idea that through these arteries circulate diverse modes of transportation, such as non-motorized vehicles (like bicycles) and motorized vehicles (motorcycles, cars, buses) as well as a greater flow of people in transit. Other studies carried out in Argentina show the center and northern regions of the country to be the areas most affected by accidents, connected in part to demographic growth and increases in the automotive fleet.(13)

With respect to the association between the physical environment and the frequency of accidents, the results of the association between the presence of street lighting and accident frequency is similar to that found in a systematic review in which three trials compared the lighting of the streets to a control area in terms of the total number of accidents, in which the pooled rate ratio (RR) was 0.45 [95% CI (0.29; 0.69)].(11) In another review, the authors reported that in two before-after studies to reduce night collisions, a reduction of 57% was seen in Israel and 59% in Australia when lighting was increased at urban intersections.(20)

An aspect to take into account in the comparison is to adjust for the time of day in which the events occurred (morning, afternoon and night), which is decisive in attributing the risk related to street lighting as a factor. This could be a potential confounder of the association considering that a greater number of accidents occur at night or in the early morning, when lighting is of importance.(10,21) For this reason, it is crucial to identify the critical nodes of traffic accidents and the state of the lighting surrounding them, given that if a correlation exists between lack of lighting and accident frequency, lighting improvements in certain points of the city can be implemented as preventive measures.(22)

Regarding the presence of trees next to the road, our study found that places without trees had a lower number of accidents. Similarly, in a case-control study that evaluated the relationship among different environmental factors and the occurrence of injuries in cyclists, an adjusted Odds Ratio of 3.25 was found for sites with more than one tree per block.(23)

According to the type of road, it was observed that 62.77% of places where accidents occurred were avenues, with 2.22 times the

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frequency of events as compared to routes. This result is in line with a number of studies that have shown this road type to present higher levels of traffic accidents, perhaps due to the speeds reached on such roads that favor accident occurrence.[12,24] In addition, it should be taken into account that combined factors exist that could potentiate one another in relation to accident frequency, such as roads where vehicles circulate at high speeds that also have poor lighting.[22] Another factor related to the road are the curves it possesses, as curves were the most important factor related to accident frequency in our analysis. Similar findings have been reported in some studies, which also specify that the direction of the curve (whether to the right or to the left) can condition accident occurrence.[25,26,27]

In our study the presence of a stoplight in the vicinity of a site increased the frequency of traffic accidents. Although the function of this type of traffic signal is to control and regulate transit, we believe a high percentage of accidents occurred due to noncompliance with stoplight indications. Some studies report high rates of noncompliance with traffic lights of up to 35%, which would increase the risk of suffering an accident.[28] In a multicentric study that included Resistencia, the authors informed high noncompliance with stoplights and transgression of transit norms in general.[29] In this scenario, we consider it necessary to expand upon these results to determine the possible causes generating greater accident occurrence in the presence of stoplights.

A number of studies have shown that high speed detection devices (cameras, radars or lasers) reduce by 40-45% the probability of fatal transit accidents and injuries.[30,31,32] Therefore, interventions geared toward traffic speed reduction are essential and effective in preventing injuries and deaths. Nevertheless, all such studies have been carried out in high-income countries. In Peru, for example, a number of these interventions can be observed, but not all are carried out in a comprehensive way so as to achieve maximum efficacy nor are they located in the necessary places.[33]

The adoption of comprehensive strategies is fundamental, through an integrated management plan for responsible driving that includes educational activities, massive implementation of street signs as well as the application of low-cost speed detection devices. Yannis *et al.* mention that an integrated speed management plan, in order to be effective and successful, depends not only on systematic follow-up in the execution of the plan and in road safety but also strong political support of the local governments. Interventions directed at the reduction of traffic injuries should form part of three fundamental pillars: educational, legal, and engineering or infrastructural interventions.[32,34]

A potential limitation of our study was that the physical inspection was carried out a year after the events occurred, making it possible that the conditions of the physical environment could have changed. It is unlikely giving the permanent nature of many of the evaluated factors and that no new infrastructure works had been announced. Another aspect to consider is the poor quality of the police records regarding the site of accident occurrence, with the possible risk of an incorrect representation of the pattern of spatial concentration or other type of statistical relationship with the independent variables included. Nevertheless, we consider this limitation to be an important indicator of the opportunity to incorporate information systems in real time that could allow our results to the corroborated. On the other hand, it should be mentioned that the technique utilized for spatial analysis (kernel density) is based on the greater frequency of occurrence of events, without establishing tests of statistical significance that allow us to know for certain whether the patterns found are randomly distributed. In addition, a limitation to take into account regarding the methodology for analyzing the related factors was the lack of information regarding the volume of circulation according to road type that would permit adjustments to the traffic accident counts in the Poisson regression model.

Considering the limitations mentioned, this study offers information valuable to urban planning, as insufficient evidence exists in low- and medium-income countries regarding the physical environment and

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accident occurrence. Knowing the hot areas of accident occurrence permits surveillance and monitoring on the part of the local government and the orientation of effective interventions for reducing injuries in these sites.

CONCLUSIONS

This study locates the city of Resistencia in a situation of urban vulnerability not only due to its socioeconomic context by also the unequal territorial development it presents in relation to neighboring cities which generates an unfavorable environment. The urban planning in existence is deficient given the lack of street lighting, traffic signs and the presence of obstacles such as trees near the roads, all of which are predisposing factors for greater accident frequency. In addition, the presence of stoplights at points of greatest accident frequency alerts us to the low adherence of drivers to transit control norms.

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